A PRELIMINARY STUDY OF THE EFFECTS OF ENERGIZING THE BOUNDARY LAYER IN THE TEST SECTIONS OF HYPERSONIC WIND TUNNELS

By John B. McDevitt

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.

Presented at the Nineteenth Semiannual Meeting
of the Supersonic Tunnel Association

Ottawa, Canada
May 16-17, 1963

FACILITY FORM 602

N65-87128
(ACCESSION NUMBER)

(THRU)

15
(PAGES)

None
(CODE)

TMX-56695
(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

TMX# 56695

INTRODUCTION

The design and construction of a new Mach number 50 helium tunnel is currently under way at the Ames Research Center. A very high Mach number, low-density tunnel of this type can be expected to have a very thick viscous layer at the tunnel walls. Downstream pressure disturbances can feedback through this layer and thus affect the flow in the nozzle. As a result of this phenomenon, the primary nozzle flow may become sensitive to the type and attitude of test models, and considerable difficulty can be expected in maintaining hypersonic flow in the test section.

Experience with existing helium tunnels (Mach numbers up to about 30) indicates that, in order to obtain a useful facility having a Mach number of the order of 50, the feedback problem must be eliminated. One possible method for effectively eliminating this problem is the use of an annular gas injector to energize the test-section boundary layer. This concept is beneficial in two respects: First, by increasing the momentum level in the viscous layer, disturbances originating from the test model, or elsewhere, are prevented from influencing the primary nozzle flow and thus stability of the hypersonic test medium is achieved. Second, the energy of the injected medium contributes to the energy of the stream entering the diffuser and the required tunnel compression ratio is reduced.

In this note a brief discussion of the viscous effects in hypersonic, low-density helium tunnels is presented, followed by the results of a preliminary experimental and analytical study of the effects of energizing the test-section boundary layer.

VISCOUS EFFECTS IN HYPERSONIC HELIUM TUNNELS

Experience with the existing Ames 14-Inch Helium Tunnel indicates that the presence of the tunnel-wall viscous layer does not noticeably affect the normal aerodyanmic test procedures for configurations at Mach numbers of the order of 10. At test Mach numbers of about 20, it was found that a feedback problem could arise if the tunnel were operated at helium-supply pressures less than about 1500 psi. However, when higher pressures, greater than about 2000 psi, were used it was found that consistent and reliable test data could be obtained in all cases. Consequently, the operation of this facility at Mach numbers near 20 has been confined to pressures of 2000 psi or more.

As the test Mach number is increased above 20, the viscous effects at the wall become increasingly more troublesome. A discussion of hypersonic viscous effects in a helium tunnel having test Mach numbers of about 30 is reported on in reference 1. In this case, it was found that the tunnel flow was influenced by the model shape and size to the extent that calibrating impact probes with the same shape as the models to be studied were required. The increasing severity of the viscous effects at high Mach numbers is related to the fact that the displacement thickness of the boundary layer, relative to the size of the central inviscid core, increases with Mach number while the stream momentum in the boundary layer diminishes.

The experience with hypersonic nozzles may be summarized, at least in a qualitative manner, as follows: At test Mach numbers of about 10, the wall viscous-layer feedback problem is not present to a noticeable degree; at Mach numbers of about 20, the feedback problem can be eliminated by operating the tunnel at sufficiently large supply pressures; and at Mach numbers of about 30, a direct coupling between the test model flow field and the wall viscous layer exists such that special flow-calibration techniques must be used for each model studied.

EXPERIMENT

A preliminary investigation of the concept of increasing the level of the streamwise momentum in the wall viscous layer was made using the Ames 14-Inch Helium Tunnel. This facility, which is of the blowdown type, uses a common nozzle with interchangeable first throats to provide test-section nominal Mach numbers of 10, 17, 21, and 25. The tunnel discharges into several large spheres evacuated to about 0.2 psi at the start of each run. A series of eight small nozzles were installed around the inside periphery of the primary nozzle, see figure 1. The small nozzles were designed to have an exit Mach number, if underexpanded, of 12.5. Both helium and air were used as the injection medium and the pressure in the downstream vacuum spheres at breakdown of the initially stable hypersonic flow in the test section was recorded. A pitot-survey apparatus was mounted in the test section during the test runs.

The test results are tabulated in table I and a portion of these results, normalized with respect to conditions of no mass injection, are presented in figure 2. For the case where the tunnel Mach number was less than the design Mach number of the injection nozzles, figure 2(a), data were obtained with the injection nozzles both overexpanded and underexpanded. In the overexpanded condition, considered here to be "off design," the effect is detrimental in that the pressure in downstream storage spheres at breakdown of the hypersonic flow in the test section was decreased. In the underexpanded condition the nozzles operate supersonically with further expansion occurring within the tunnel boundary layer. In this case the effect is beneficial. The test results for nominal Mach numbers of 17, 21, and 25, shown in figure 2(b), were obtained with the injection nozzles operating underexpanded in all cases. Since a common injector system and test section were involved in these tests, the mass flow of the injector system, relative to that for the tunnel, varied considerably and hence it is informative to present these results in terms of the ratio of mass flows, see figure 3.

The test results are summarized in figure 3 for both helium and air as the injection medium. It is apparent that this rather crude injection system is quite effective in raising the level of the downstream diffuser pressure at which the tunnel is able to operate. For example, with helium injection at a mass-flow rate equal to about 75 percent of that for the tunnel, the over-all compression ratio required to maintain hypersonic flow in the test section is reduced to one half that for no mass injection.

A pitot survey of the test section region adjacent to the injector nozzles indicated that the injection process did not alter the flow characteristics in the central, high-speed core.

CORRELATION OF DATA WITH STREAM ENERGY CONSIDERATIONS

It will be demonstrated here that a parameter proportional to the stream energy may be used to correlate test data relating to the required operating conditions for maintaining hypersonic flow in the test section. A convenient measure of the hypersonic stream energy is the product of either the impact pressure or dynamic pressure and the cross-sectional area of the stream. (Since the ratio of dynamic pressure to impact pressure is invariant at high Mach numbers, it is immaterial which parameter is used.) At hypersonic Mach numbers (greater than about 10) the following approximate relationships may be used:

<u>Air</u>

$$\frac{p_{t_2}}{p_{t_1}} = \frac{360}{M_i^5} , \qquad \frac{A_i}{A^*} = \frac{M_i^5}{216}$$

$$p_{t_2} A_i = 1.67\ p_{t_1} A^* \tag{1}$$

<u>Helium</u>

$$\frac{p_{t_2}}{p_{t_1}} = \frac{22.9}{M_i^3} , \qquad \frac{A_i}{A^*} = \frac{M_i^3}{16.0}$$

$$p_{t_2} A_i = 1.43\ p_{t_1} A^* \tag{2}$$

where A^* and A_i are the cross-sectional areas of the sonic throat and the hypersonic inviscid stream, respectively, and M_i is the hypersonic Mach number corresponding to A_i.

It is interesting to note that, for a given A^*, p_{t_1}

$$\frac{\left(p_{t_2}A_1\right)_{air}}{\left(p_{t_2}A_1\right)_{helium}} = 1.17 \qquad (3)$$

which implies that the use of air as an injection medium for raising the energy level should give slightly better results than the use of helium. However, the mass flow using air is considerably larger. The mass-flow rates are, in the two cases,

Air

$$\dot{m} = 1.04\ p_{t_1}A^*\sqrt{\frac{520}{T_t}} \qquad (4)$$

Helium

$$\dot{m} = 0.41\ p_{t_1}A^*\sqrt{\frac{520}{T_t}} \qquad (5)$$

When an injector system is used in conjunction with the hypersonic tunnel, the stream energy of both systems is considered to be additive. A parameter proportional to the total energy, normalized with respect to the cross-sectional area at the test section, is the following:

$$E = \frac{\left(p_{t_2}A_1\right)_{tunnel} + \left(p_{t_2}A_1\right)_{injectors}}{A_{ts}} \qquad (6)$$

The measured pressures in the downstream low-pressure spheres at breakdown of the tunnel hypersonic flow are presented in figure 4 with E as the correlating parameter. Data are presented for no mass injection and with mass injection at the highest rates used for each of the nominal test-section Mach numbers. Within the accuracy of the test procedure the data correlate remarkably well (the offset near the origin is believed to be the result of viscous losses in the tunnel, diffuser, and piping to the vacuum spheres). Note that the Mach number does not enter as a significant parameter. This is in contrast to the usual method of presenting tunnel compression ratio as a function of Mach number, the results of which cannot be reliably extrapolated to higher Mach numbers, even if a log scale is used.

CONCLUDING REMARKS

The experimental study described here was undertaken to provide preliminary information regarding the effects of energizing the viscous layer at the wall of a hypersonic wind tunnel. The rather crude injection system used was quite effective in raising the level of the downstream diffuser pressure at which the tunnel was able to operate. The maximum pressure in the downstream low-pressure storage spheres for which hypersonic flow could be maintained in the tunnel test section was found to vary linearly with a parameter proportional to the total stream energy, regardless of the injection gas used, provided that the injectors were operating in an underexpanded condition. A limited impact survey of the test section indicated that the high-speed central core in the region immediately adjacent to the gas injectors was not affected by the injection process.

The present study has indicated the feasibility of using an injector system adjacent to the model testing region. However, no direct evidence was obtained regarding the effectiveness of this approach for reducing or eliminating the feedback problem associated with the tunnel viscous layer at hypersonic speeds. An annular injector system, shown schematically in figure 5, is under construction at the present time and will be tested in the near future. The annular injector can be expected to be more effective than individual nozzles in that stream momentum is applied around the entire periphery of the test section. With the annular injector it is hoped that information can be obtained towards solution of the viscous feedback problem and that design information pertinent to the new Mach 50 tunnel may be acquired.

APPENDIX

NOTATION

Primary Symbols

A	cross-sectional area, sq in.
A^*	cross-sectional area of sonic throat, sq in.
A_{ts}	cross-sectional area of tunnel test section, sq in.
E	stream energy per unit volume (see eq. (6)), lb/sq in.
$\dot{m}$	rate of mass flow, slugs/sec
M	Mach number
p_{t_1}	total pressure (stagnation pressure if the gas were brought to rest isentropically), lb/sq in.
p_{t_2}	stagnation pressure behind normal shock, lb/sq in.
$\overline{p}_{sp}$	pressure in downstream low-pressure storage spheres when hypersonic flow in the tunnel test section breaks down
T_t	total temperature, °R

Subscripts

i	condition corresponding to isentropic channel flow
N	nominal value

REFERENCE

1. Johnson, Robert H.: Hypersonic Viscous Effects in Wind Tunnels. ARS Jour., vol. 31, no. 7, July 1961, pp. 1022-1024.

TABLE I.- SUMMARY OF TEST RESULTS

M_N	Injection medium	p_{t_1}, psi		$\bar{p}_{sp}$, psi	$\frac{A^*_{injectors}}{A^*_{tunnel}}$	$\frac{\dot{m}_{injectors}}{\dot{m}_{tunnel}}$
		Tunnel	Injectors			
10	Helium	100	0	0.85	0.03	0
			100	.79		.03
			200	.81		.06
			400	.91		.12
			800	1.16		.24
		300	0	2.76		0
		300	1000	3.13		.10
17		1000	0	2.00	.14	0
			500	2.14		.07
			1000	2.39		.14
21		2000	0	1.15	.42	0
			500	1.33		.11
			1000	1.43		.21
			1500	1.62		.32
			2000	1.72		.42
25		2500	0	.41	1.25	0
			500	.56		.25
			1000	.66		.50
			1500	.81		.75
			2000	.98		1.00
21	Air	2000	500	1.35	.42	.11
			1000	1.50		.21
			1900	1.77		.40

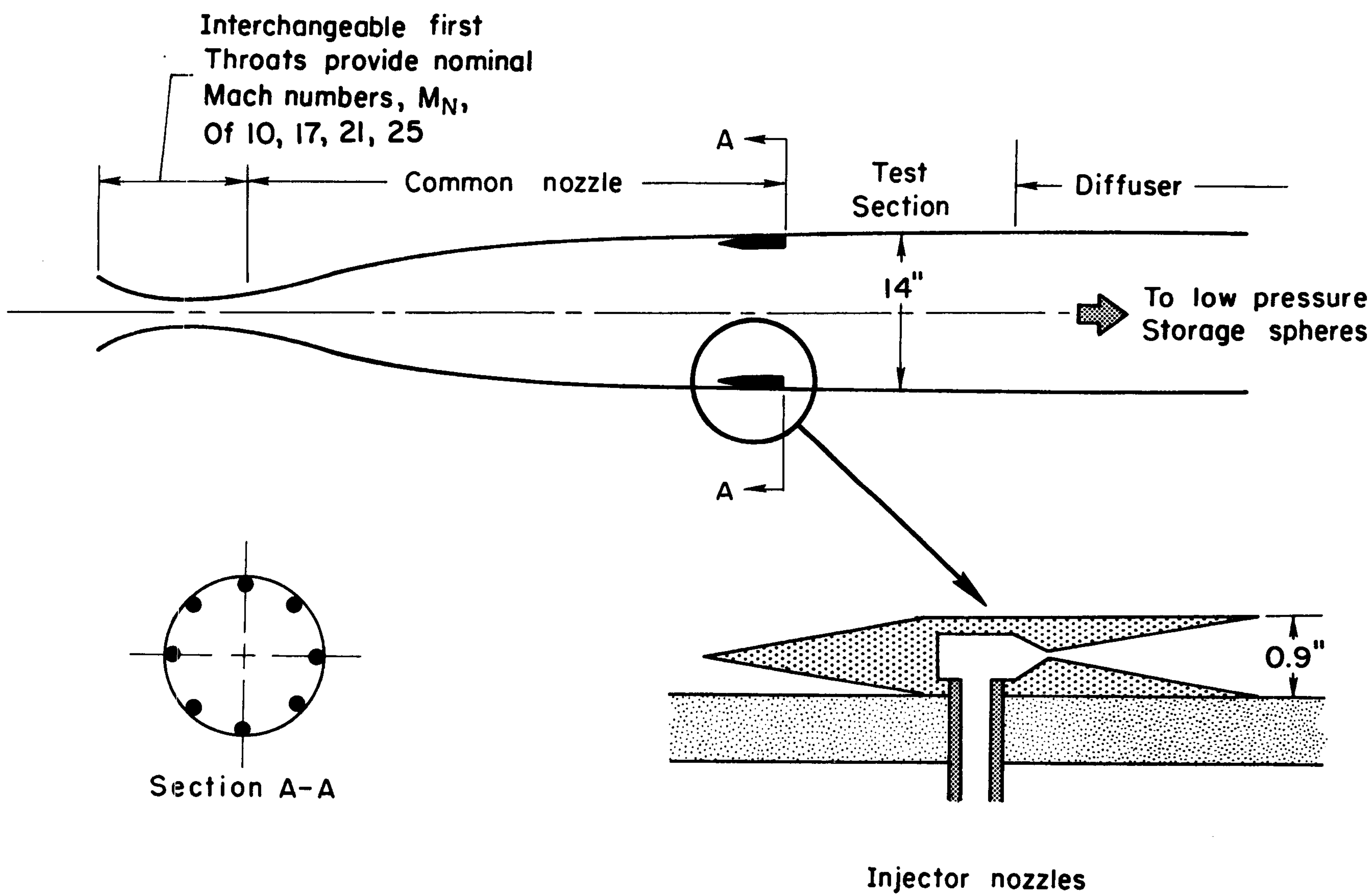
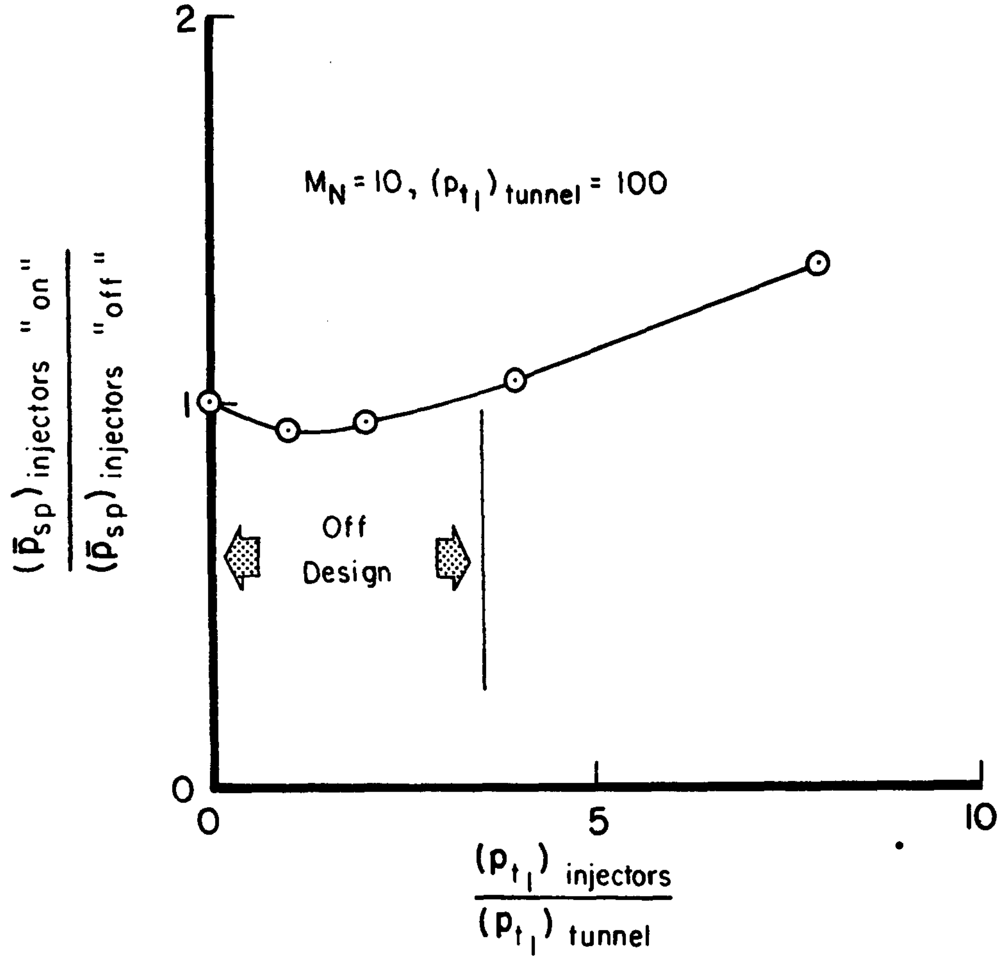


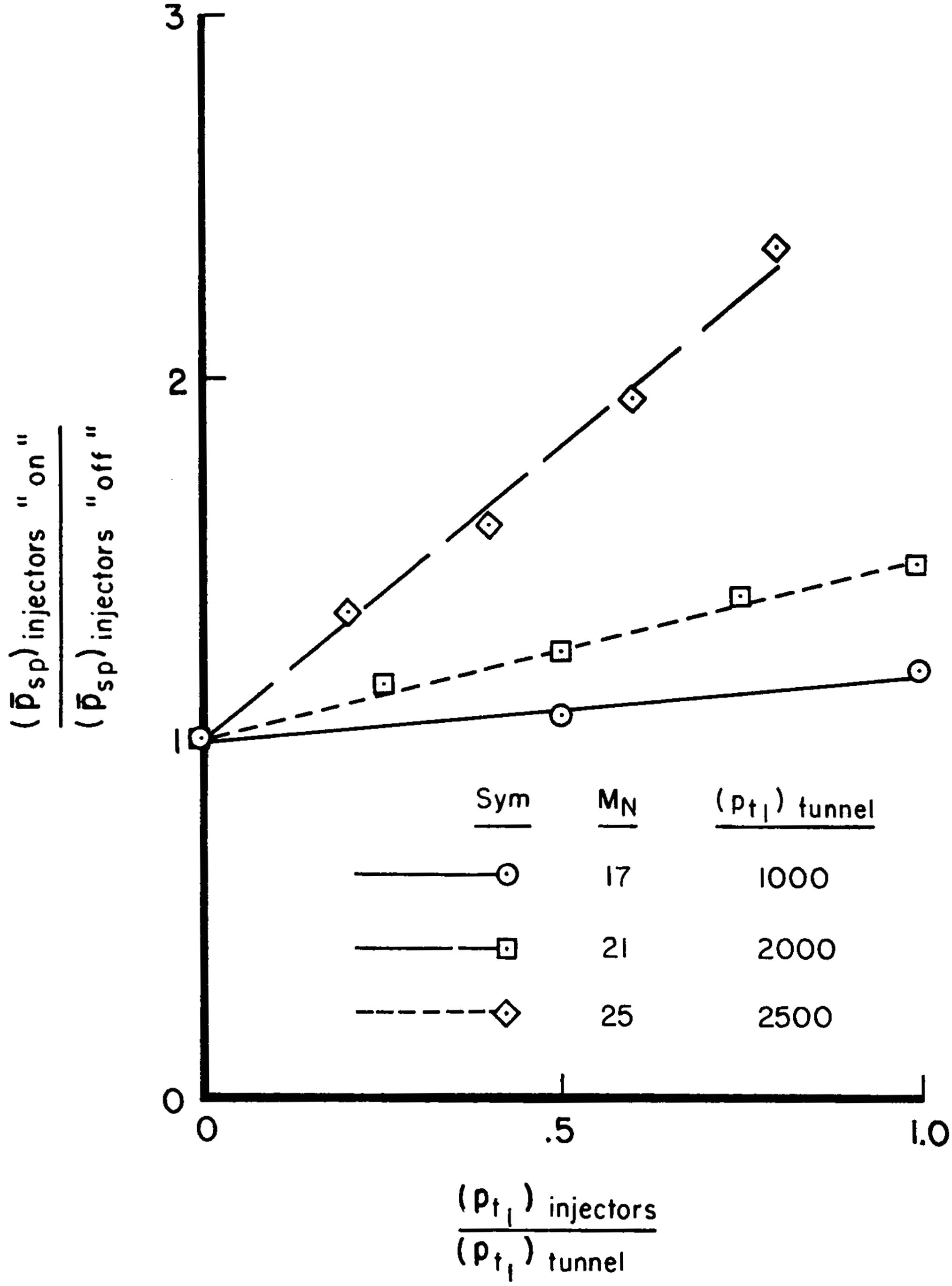
Figure 1.- Schematic drawing of the Ames 14-Inch Helium Tunnel with injector nozzles installed.

A-30859-1



(a) $M_N = 10$

Figure 2.- Variation of pressure in the downstream spheres at breakdown of the tunnel hypersonic flow with injector pressure for helium injection.



(b) M_N = 17, 21, and 25

Figure 2.- Concluded.

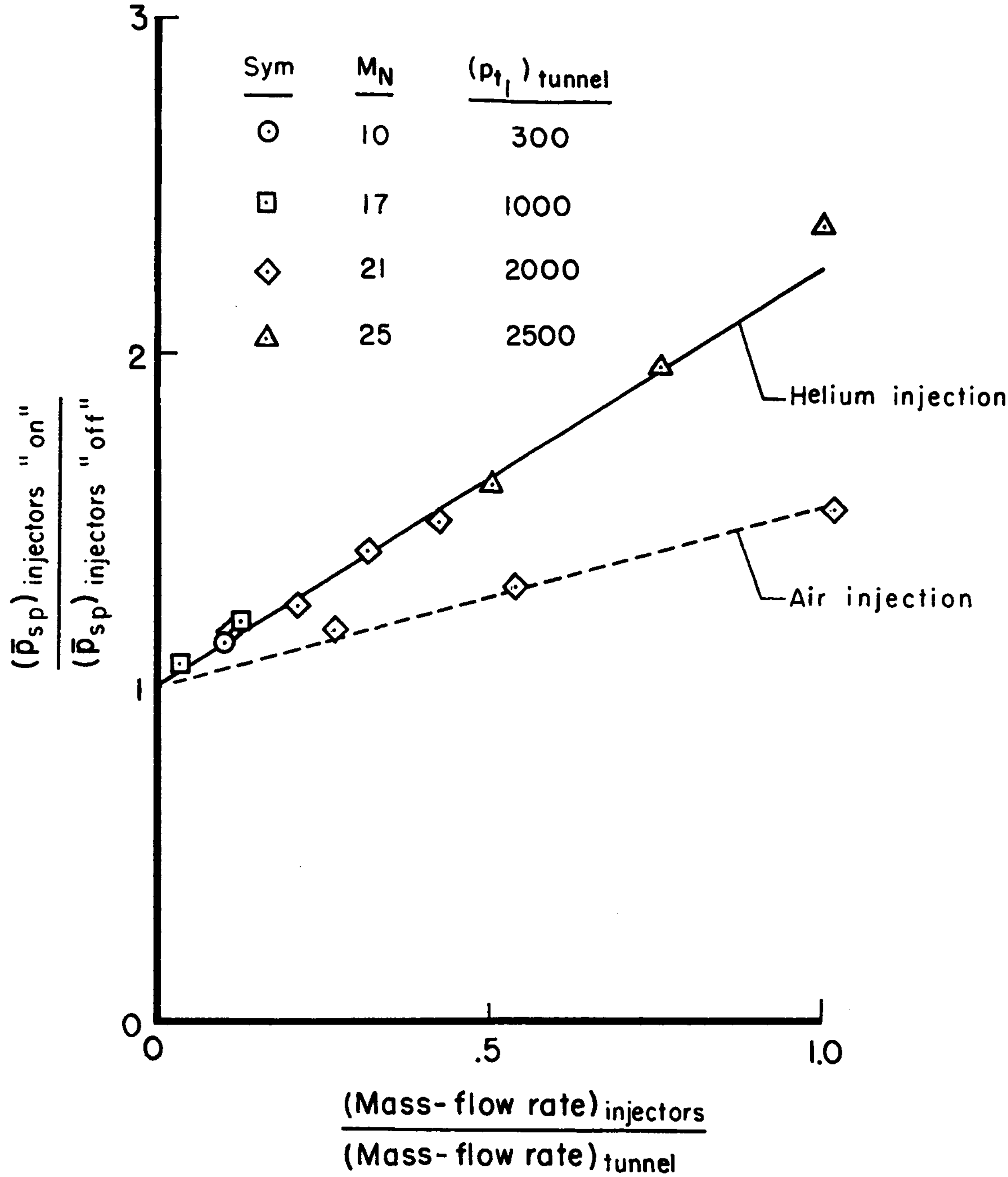


Figure 3.- Variation of pressure in the downstream spheres at breakdown of the tunnel hypersonic flow with injector mass-flow rate.

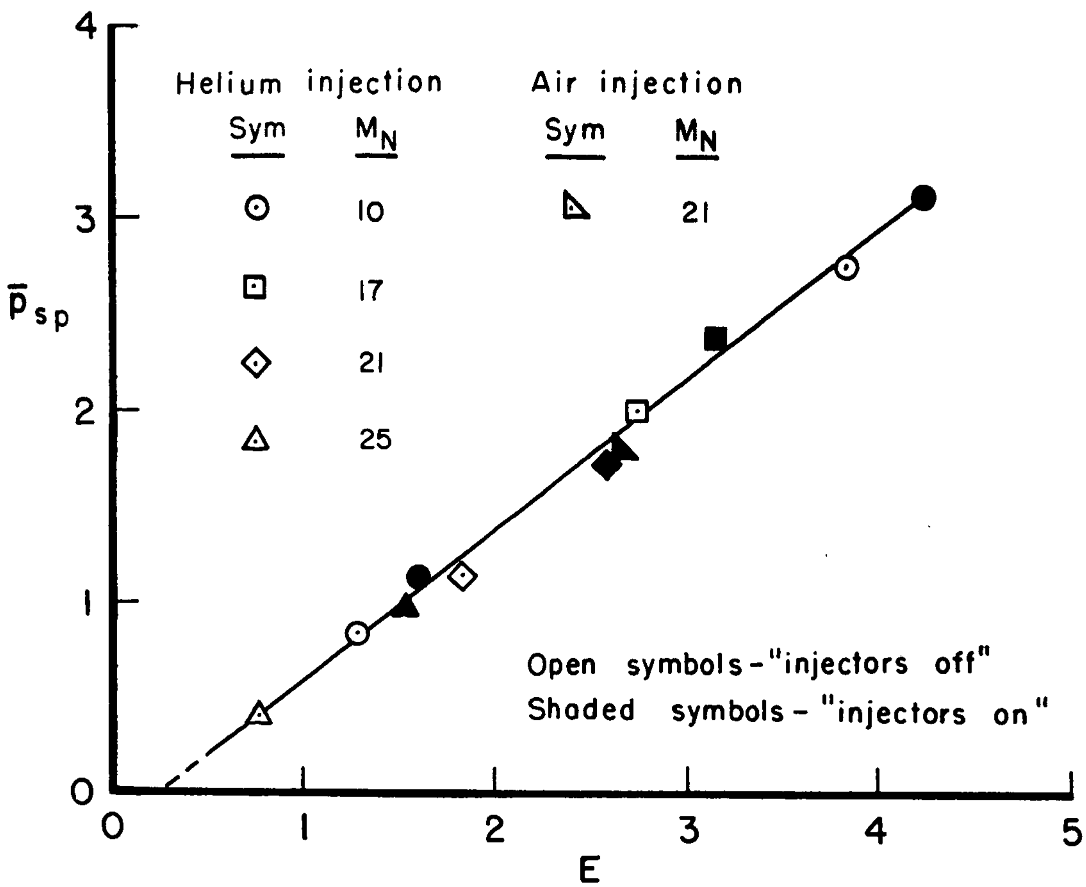
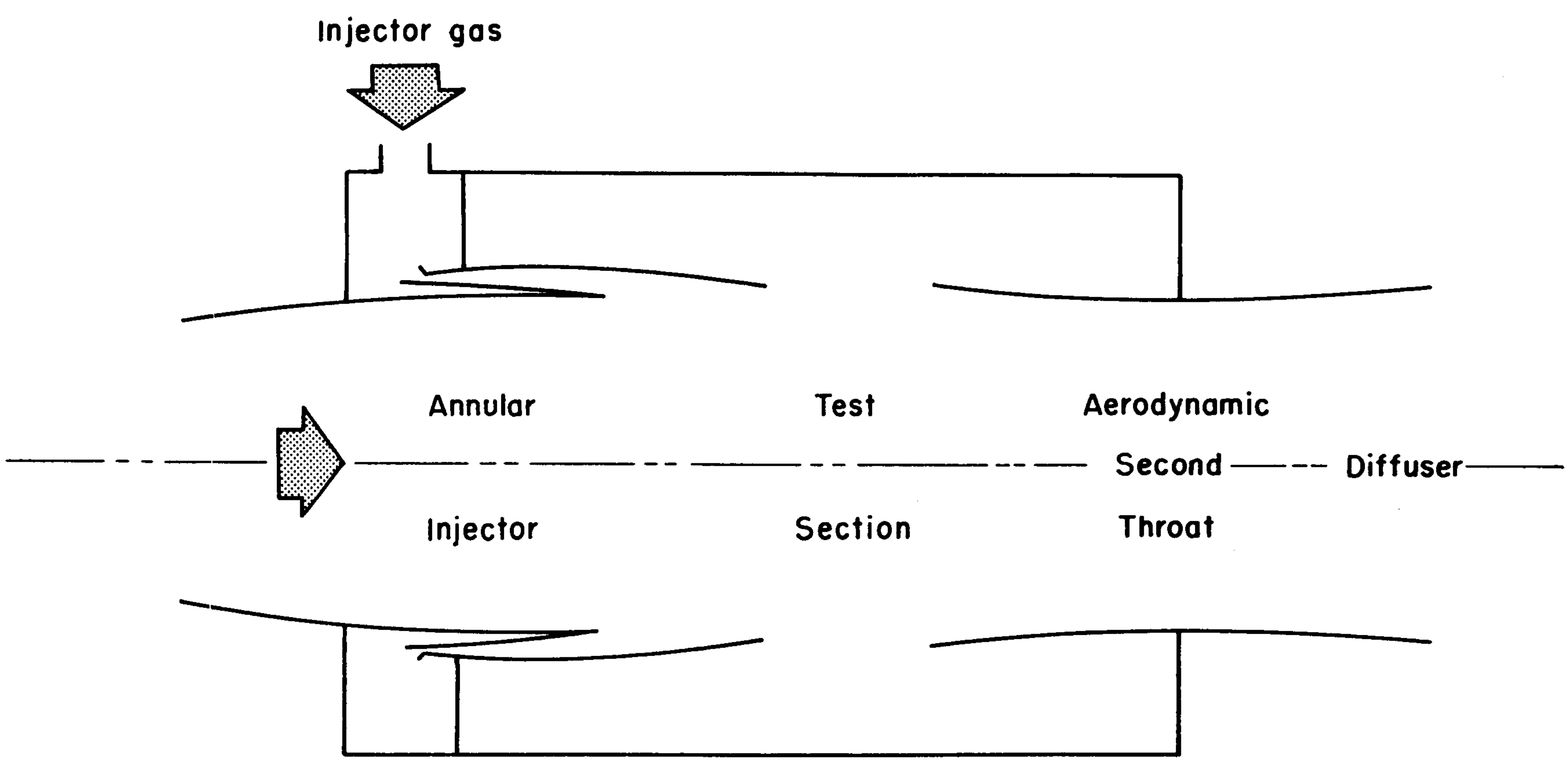


Figure 4.- Correlation of measured pressures in the downstream spheres at breakdown of the tunnel hypersonic flow with the stream energy parameter.



A-30859-4

Figure 5.- Schematic drawing of the annular injector.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA